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Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected at a meeting of the Council held on Tuesday, March 21st:—

Associate Fellow.—Squadron Leader J. Sowrey, A.F.C.

Students.—G. F. Law, A. E. Woodward Nutt, A. D. Patwardham, E. J. D. Townesend, T. E. Waldeck.

Member.—Captain S. H. Starey.

Foreign Members.—Lt. Commander R. Arisaka, I.J.N., Captain D. Tiselius, R.S.N.

Annual General Meeting.

The Annual General Meeting was held on Tuesday, March 28th. Minutes of the proceedings will be published in the May issue of the Journal.

Lecture.

The remaining lecture of the present Session will take place at 5.30 p.m. on Thursday, April 6th, when M. Louis Bréguet will read a paper on "Aerodynamical Efficiency and the Reduction of Air Transport Costs."

Students' Section.

The following programme has been arranged:—

Friday, April 7th.—Annual Address to Students. Professor L. Bairstow on "Some Aeronautical Problems of the Early Future." 6.45 p.m. in the Society's Library.

Saturday, May 6th.—Visit to de Havilland Aircraft Works. Meet at the Works at 10.0 a.m.

Wednesday, May 31st.—Visit to Royal Aircraft Establishment. Meet at Waterloo at 8.40 a.m. at the Booking Office.

Saturday, June 3rd.—Visit to National Physical Laboratory. Meet at Waterloo at 9.30 a.m.

Any member of the Society is invited to attend Prof. Bairstow's lecture to the Students' Section.

Library.

The following books have been received and placed in the Society's Library :—" Howard " Lectures on Aero Engines, by A. E. L. Chorlton, Royal Society of Arts; Alloys Research Committee's Reports, 1907, 1910 and 1921; " Structural Analysis and Design of Airplanes," Major T. G. Bane; " Deutschlands Krieg in der Luft," by von Hoeppner; " Grundlagen der Flugtechnik," by Dr.-Ing. H. G. Bader; " Notes and Examples on the Theory of Heat and Heat Engines," by John Case; " La Photographie Aerienne," by A. H. Carlier; " Cours pratique d'aviation," by Capitaine Gambier and Lt. de Vaisseau Amet; and " Research in Industry," by A. P. M. Fleming and J. G. Pearce.

Associate Fellowship Examination.

The Council have decided, as a result of representation which has been made to them, to hold the examination for Associate Fellowship in September instead of in April this year, as it has been found that this would be more convenient for the majority of students who desire to sit for the examination, owing to their studies having been delayed by the war. Intending applicants should forward their names to the Secretary not later than July 31st.

W. Lockwood Marsh, *Secretary.*

PROCEEDINGS.

SEVENTH MEETING, 57th SESSION.

A meeting of the Royal Aeronautical Society was held in the Rooms of the Royal Society of Arts, Adelphi, London, on Thursday, January 19th, 1922, the President, Lieutenant-Colonel M. O'Gorman, in the chair, when a paper on "Engine Installation" was read by Brigadier-General R. K. Bagnall-Wild, C.M.G., C.B.E., M.I.Mech.E., F.R.Ae.S., M.I.Aut.E.

The CHAIRMAN, in announcing the title of the paper, said that Brigadier-General Bagnall-Wild was, he was proud to say, introduced to aeronautics partly through his own instrumentality a good many years ago, and he had also known him for 19 years as a pioneer in the realm of the motor car. Accordingly, there was every reason to suppose that he knew something about engine installation. Also, on behalf of the Society, the Chairman congratulated Brigadier-General Bagnall-Wild as a distinguished Fellow of the Society upon his recent appointment to the distinguished post of Director of Research at the Air Ministry. (Applause.)

Brigadier-General BAGNALL-WILD thanked the members and explained, with regard to his paper, that he had been eight years in the A.I.D., and that it was written from that point of view. Also, it was not an individual or personal paper, but a collection of ideas gleaned from the whole of the staff of the A.I.D., dating back to 1914. He would especially thank Major Bulman, O.B.E., and Captain Warner, both of the A.I.D., for the valuable assistance they had given him in the preparation of the paper.

ENGINE INSTALLATION.

It may be stated definitely that installation as a whole has shown little progress as compared with the development of either the aircraft structure or engine, and that to-day the installation of the engine in a machine presents a wide field for sound engineering design and improvement. On the other hand, failure in some part of the installation is the most prolific cause of forced landings. Statistics taken over a considerable period have shown that of the proportion of forced landings resulting from engine stoppage, seven out of eight are due, not to any actual defect in the engine itself, but to some trivial breakdown in the installation.

Apart, too, from the question of reliability and safety, installation development provides room for considerable economy, not only as regards its actual upkeep and repair, but also from its effect on the easy (or otherwise) removal of the engine from the aircraft for overhaul and replacement purposes. The whole of the time and labour spent either in patching up the details of the installation or removing the engine for overhaul and/or replacement, represents a dead loss in the useful flying time of the machine; a factor of importance not only to the Service in that an increased number of machines is required than would otherwise be necessary to meet given operational requirements, but also for civil aviation, in that the nett earning value of the machine is reduced.

The reasons for this lack in development of the installation are not far to seek. In the earliest days, when engines themselves were utterly unreliable, there was no real incentive to provide a sound system of installation; indeed, the disposal and fitting of petrol and oil pipes, ignition control leads, switches,

etc., were more often than not left to the mechanic engaged on the work to effect with the utmost economy in materials, leading too often to makeshifts of string and electricians' tape.

Throughout the greater part of the war it was usually found that the engines for a certain type of machine were unavoidably many months late in delivery, since the period of development of an aero engine must inevitably be much in excess of that required for the aircraft itself. As a result, it was usually necessary in the end to put in some other type of engine, intended probably for a totally different design of machine and to effect the best possible compromise.

A third factor in the situation has been a universal lack of co-operation and mutual understanding between the engine and aeroplane designer, rendered more complete in that almost without a single exception, the two designers in question were not of the same firm or management. The aeroplane designer, perhaps naturally, concentrated his energies on the aero-dynamical and military requirements of his machine, while the engine designer devoted the whole of his attention to the production of an engine of light weight per horse-power, low fuel and oil consumptions, and improved reliability, both overlooking the fact that unless the one provided the optimum conditions for the other the efficiency of the aircraft as a whole must be reduced and the value of the work of both designers correspondingly depreciated. How many aircraft designers, for instance, set out to ascertain the normal working pressure and temperature of the oiling system on the particular type of engine which they proposed to fit and proceeded further to embody in their aircraft designs the necessary means for the attainment of those desired conditions. It may be contended, perhaps, with equal force by the aircraft designer, that if the maintenance of specific oil and temperature pressures were essential to the well-being of the engine, the necessary oil coolers should have been embodied in and actually delivered with the engine.

The fitting of carburettor air intakes provides a further instance in that with only one or two exceptions engines now actually in use are sent out by the engine constructor without these parts, although the exact form of air intake must obviously have a considerable effect on the carburation and general efficiency of the engine. Practically every type of machine will be found to have a form of air intake peculiar to itself, put on, it would often seem, as an afterthought—as a necessary but unimportant evil. As a result, a special tuning up of the engine in the machine after it has passed its test at the engine constructors is involved, and in addition interchangeability of engines between different types of machines is seriously affected.

It may be said that on this point of air intake design the engine constructor is tied down, in that its various individual types have already been settled by the respective aircraft designers, so that it is too late now to introduce one standard type for each engine without involving structural alterations to the machines, in some cases to a considerable extent. There is no obvious reason, however, why in any future design of engine a standard air intake should not be fitted by the engine maker and definitely adopted for that engine. If that were the case, the aeroplane designer would naturally provide for that particular form of air intake just as he now does for the over-all dimensions of the engine itself and the position of its bearer feet.

These general remarks will perhaps serve to show what, in the author's opinion, have provided the greatest obstacles in obtaining sound installation. Fortunately, this phase in aircraft development is disappearing and improved installations are already the result.

The advent of civil aircraft is, to a large extent, responsible for this improvement, for of stern commercial necessity the aircraft and engine designers have been brought into closer touch with each other's difficulties, and the situation will continue to improve with an increasing appreciation by all concerned that without

thoroughly sound installations no increase in reliability of either the engine or the aircraft structure will avail.

Let us now consider what are the principal features required for the evolution of a sound installation and then discuss how far, in the light of present-day experience, these aims may be realised.

The desiderata of a sound engine installation would appear to be the following :—

(*a*) Reliability and simplicity of arrangement of petrol, water and oil systems to ensure maximum engine efficiency.

(*b*) Every possible safeguard to be taken against fire risks.

(*c*) A high factor of safety in the mounting of the engine itself, together with all accessories and attachments required for its working, not only as regards initial soundness, but also in the individual capacity of the component details for long service.

(*d*) Ready accessibility of the complete engine and installation, particularly for those parts which require frequent inspection, such as carburettors, magnetos, petrol pumps, petrol and oil cocks, filters, controls, etc.

(*e*) The arrangement of the installation to be such that an absolute minimum of disconnection and displacement is entailed in the removal of the engine. It should be possible to remove an engine for overhaul and to replace it with a serviceable unit in, say, not more than two hours. Indeed, I look forward to the attainment of something approaching the replacement of a locomotive as now effected on long distance " through " train services, so that the aerial passengers or cargo can proceed almost without interruption over considerable distances.

(*f*) Arrangements for engine starting to be of a simple and reliable character.

By considering each of the foregoing paragraphs in detail, and applying the results to the installation of a single-engined aircraft, the fundamentals of installation will be fairly well covered. The installation of multi-engined machines, where they differ in principle from single-engined machines, can be dealt with as occasion arises.

Petrol System.

So far four distinct methods have been applied to the supply of petrol to the engines :—

(1) By situating the whole of the petrol containers above the carburettor and feeding by gravity.

(2) By air-driven petrol pumps, pumping direct from the main tanks to the engine or via a gravity tank.

(3) By air pressure raised in the main tanks by air pumps, petrol being forced from the main tanks to the engine direct or via a gravity tank.

(4) By providing a vacuum apparatus to raise petrol from the main tank to a gravity tank and thence to the engine.

It will be agreed that for reliability and simplicity gravity feed is the ideal, but so far the difficulties, from the aerodynamic point of view, in the situation respectively of the engine and fuel tanks to utilise gravity feed have been considered too great. I sometimes wonder if the simplicity and efficiency of gravity petrol feed have been sufficiently realised by aircraft designers, and whether a satisfactory design could not be evolved if the provision of gravity feed were made a condition of acceptance of the aircraft. Indeed, in view of the comparative unreliability and complexity of other systems, it may eventually be found

necessary by civil companies to specify gravity petrol systems even at a slight expense of aerodynamical efficiency.

A very deep fuselage with the engine placed low in the front and the petrol carried as far back as possible and at the side or the top of fuselage should readily lend itself to the system, since most carburettors will function at a minimum head of 18in.

Obviously, if propellers driven by transmission shafts and gears prove to be successful present difficulties should be much reduced in that the engine may be installed in the bottom of the fuselage or hull, and the petrol carried in the fuselage or hull, or on the wings to provide a gravity feed. In addition, the fuel could be placed at some distance from the engine, thereby greatly reducing fire risks.

The value of gravity petrol systems to multi-engined machines would be greatly enhanced, especially in Service aircraft, for reasons indicated later.

Air pressure systems for Service aircraft were abandoned during the war, owing to extreme vulnerability, in that if one tank or for that matter practically any part of the air supply system gave out or became damaged by gunfire the whole supply failed except for the limited emergency supply usually carried in a gravity tank.

Direct petrol pumping systems then came into use. Slow speed propeller driven plunger pumps were first used on seaplanes; they were fairly reliable in action, but owing to their intermittent delivery they had to be coupled to the engine via a gravity tank, which then became the sole duct to the engine.

High speed propeller-driven centrifugal petrol pumps were next introduced, coupled usually to feed direct to the engine, and in addition, to an emergency gravity tank kept "topped" up and overflowing back to the main tanks, any excess pressure in the system being dealt with by relief valves. Non-return valves prevented the return of petrol from the gravity tanks. In these systems, therefore, the main supply is obtained direct from the pumps with an emergency supply always available from the gravity tanks.

The average speed of these centrifugal pumps is 3,500 r.p.m., and mechanical failure is, unfortunately, still too frequent. To guard against this two pumps are usually fitted. It is inadvisable that these pumps should work with a suction lift, and accordingly they are usually placed below the petrol in the main tanks, which in itself is a disadvantage. Further, it is clear that the duplication of pumps, etc., to attain some measure of reliability adds enormously to the complexity and weight of the system, particularly in multi-engined machines.

Apart from these inherent troubles in petrol systems as a whole, there are also considerable difficulties with details to which I would earnestly direct the attention of all concerned with a view to effecting improvements.

Take petrol pipe lines. Probably petrol pipe lines have been a greater source of trouble from a maintenance point of view than any other part of the aircraft. It is therefore a matter for surprise that until recently no consistent effort has been made to overcome what is universally recognised to be a vital defect, namely, the use of a tubing formed of rubber and canvas for the connection of the main copper piping at frequent intervals to reduce the vibration and consequent concentration of stress in the metal conduits. This material deteriorates very rapidly, particularly if the petrol contains anything approaching the percentage of aromatic content required to obtain maximum engine performance. The changing of all such joints is required in any case every three or four months—on a big machine a lengthy and costly operation.

Two methods have recently been introduced to overcome the difficulties. One is to do away altogether with flexible non-metallic joints and to provide an all-metal rigid connection. It is well known that where pipes have broken in aircraft they normally failed at or near the point of rigid attachment. These rigid

joints, however, were made by the usual brass nipple and union nut method, necessitating a brazing operation, etc. The making of such a joint weakens the pipe at point of concentrated stress, and it was therefore decided to design a rigid joint which eliminated the fitting of a nipple and a brazing operation.

A great advantage of this new joint is that it can be easily dismantled and re-assembled and the whole of it exposed for inspection. After the nuts and collars are placed on the pipe the latter are expanded by a special tool. It is necessary to anneal the pipe before expanding, and it is advisable to anneal again after the operation. It is also important that the two ends of the joint are set in correct alignment before tightening up.

So far this type of joint has stood up very successfully during tests. One machine to which it was fitted throughout was badly crashed, but the joints remained intact and did not leak. Further tests are being conducted with promising results.

The second method of eliminating the rubber and canvas joint is to introduce a new material, manufactured by the Blaisdell's Petroflex Tubing Co., a tubing made up with an inner lining of gut and an outer covering of canvas. It is treated for fire resistance and is armoured outside.

The lining of gut is, of course, non-expansive, so that the pipe ends must be plain, save for a slight rounding off of the edges, making the assembly of the joint a very simple matter. Either a special nut or ordinary pipe clip can be used to secure the tubing to the pipe.

Experience with this material shows promising results and it is now in use both on Service and civil aircraft. It has one considerable advantage in that existing rubber and canvas joints can be readily replaced with this material without other alteration.

Copper has been mainly used for petrol pipe lines and is undoubtedly the best material at present for the job. Aircraft manufacturers have, however, for some time past, mainly on account of the difficulties with joints in copper pipe, been investigating the use of steel for pipe lines. It is to be hoped that improvements in the jointing of copper pipes will proceed, reducing the necessity for any change in material until something more satisfactory than copper can be found.

Slow progress in the evolution of a satisfactory petrol cock has always been due to the difficulty in finding a material capable of withstanding the disintegrating effect of petrol, whilst with metallic materials, no lubricant is effective in counteracting the abrasive action set up by petrol between two metal rubbing surfaces. Messrs. Vickers have designed a cock with a phosphor bronze body and plug of stainless steel, hardened and ground to a very fine surface, which in conjunction with the hardness of the plug reduces the abrasive effect when the cock is operated. A special spring-loaded packing gland prevents leaks and ensures smooth and easy operation. Numbers of these cocks are in satisfactory use on Service and civil machines to-day.

Engine Mounting.

An engine mounting must have a high factor of strength above the maximum torque it is likely to receive, and be sufficiently rigid in all directions to withstand intermittent and concentrated loading without distortion sufficient to stress unduly the engine crankcase. Bearers, in fact the whole mounting, should preferably be produced in metal (steel) which further overcomes all the difficulties arising from the shrinkage and deterioration which take place with wood; the fire danger is also reduced and a longer life ensured to the mounting.

Messrs. Rolls-Royce have introduced into the "Condor" engine an in-

teresting development comprising a bush which serves as a sort of universal joint. This bush, which is first fitted to the engine bearer tubes, has a spherical portion over which the actual engine feet are bolted. A close working fit obtains between the bush and the engine foot, so that should the bearers for any reason be thrown out of alignment or distorted temporarily by landing shocks, etc., the undue stressing of the crankcase which would occur if the feet were rigidly fixed, is obviated.

Another feature of the same system is that provision is made for any longitudinal expansion of the crankcase by leaving the two bushes for the rear engine feet free to slide along the bearer tube, while the two front bushes remain fixed to the bearers.

Engine Controls.

There is an extraordinary and, in my view, an inexplicable lack of uniformity in the type of engine controls fitted to various aircraft. The only respect in which all seem to agree is in the direction of operation, viz., a forward or upward movement of the control to secure the "open" position.

Some controls are well designed in detail and in their general lay-out; most are comparatively primitive. Positive acting rod type of control is, so far, the most satisfactory, especially when the details of levers, brackets and bearings are well designed and made. Cable controls, although convenient to instal, especially on multi-engined machines, are unsatisfactory in several respects, in that frequent adjustment is required to correct the stretch and maintain synchronisation, while in addition a wire may become frayed in an inaccessible place and remain unseen until it breaks.

Controls should all be clearly marked to indicate their purpose and direction of operation, and even then the levers should be quite distinctive, either by position or shape, so that the operator can recognise them immediately in cases of emergency by touch while wearing flying gloves.

It is usual to inter-connect the throttle and altitude controls and in some instances the ignition is also inter-connected with the throttle, so that although each control can be operated independently, the act of closing the throttle will also close altitude and retard ignition.

Oil Systems.

These are usually of a simple character. A tank carrying sufficient oil is situated above the engine pump. It is important to fix the tanks above the pump to obviate any risk from the pump failing to lift correctly owing to suction leaks, etc.

Adequate arrangements are required to ensure the oil maintenance of the temperature as specified by the engine makers. To this end an oil temperature recording device should be permanently installed in at least the first machine of a type, so that temperatures can be taken during type tests.

Water Systems.

As this paper deals only with installation, it is not proposed to deal with the actual details of radiator manufacture.

Honeycomb radiators with tube blocks made from tubes 10 m.m. × 120 m.m. are most commonly used.

To determine originally the size of a radiator for any particular machine is a matter of considerable difficulty owing to the absence of sufficient reliable data

on the subject, and also the many variables encountered, *i.e.*, difference between summer and winter conditions, extent of cowling, position of radiator, difference of temperature with altitude, size of pipes, etc.

As a result, however, of numerous tests carried out, an average figure which serves as the basis for calculation has been arrived at for most of these variables, viz. :—

Atmospheric temperature is taken to be that of the average English summer conditions, viz., 23°C., and a decrease in temperature with altitude as shown in following table :—

TEMPERATURE CONDITIONS.

ENGLISH SUMMER.

Altitude in feet.	Temp. Fall. °C.	A Atmos. Temp. (Assumed °C.).	B Boiling Point. (Approx. °C.).
0	0	23	100
2000	3	20	98
4000	6.4	16.6	96
6000	9.4	13.6	94
8000	13	10	92
10000	16.4	6.6	89.6

Extent of cowling is a much more difficult matter. With an engine absolutely exposed to an air speed of 60 m.p.h., between 44 per cent. and 55 per cent. of the water jacket heat can be dissipated by the engine itself, whereas if an engine is completely or partially "cowled" the whole or a proportion of that temperature has to be dealt with by the radiator. For efficient cooling it has been determined that the "exposed" engine would require a rate of water circulation per 100 h.p. of 11 g.p.m., whilst the "cowled" engine would require 22 g.p.m. Obviously engine water pumps cannot be designed to suit each of these conditions, so that a minimum of 15 g.p.m. per 100 h.p. is now specified for the rate of flow through all radiators for Service aircraft.

There are, of course, other important factors entering into this subject which cannot be gone into in this paper. Sufficient, however, has been said to indicate the difficulties attendant on aircraft radiator design; suffice it to say that this question provides probably the most effective ground for contention to-day. On the other hand, good average results are now being obtained with radiators on new aircraft, due probably to a tendency to err on the safe side by having large radiators and controlling the temperature by means of shutters to reduce at will the amount of radiator surface exposed.

All radiators should be tested for flow and capability to withstand pressure. Flow tests assist also in the detection of any internal obstructions in the radiator. This test is taken with water flowing through the radiator from a constant head of 7ft. (measured from the radiator inlet), the rate of flow being measured against time into a calibrated vessel placed at the radiator outlet.

Pressure tests are taken by filling the radiator with water and subjecting it to a head equivalent to 6lbs. per sq. inch, also measured at the radiator inlet, the pressure being held for ten minutes without leaking.

Fire Prevention.

Apart from the disposition of the petrol already dealt with, there are other safeguards against fire risks that require to be taken in the engine installations. This important subject has been considered by the Fire Preventions Committee.

Their recommendations, recently published and endorsed by the Air Ministry, are now made a condition of manufacture in all new Service aircraft. A summary may be made as follows:—

(1) The engine should be isolated from the remainder of the aircraft by a light sheet-metal bulkhead lined with asbestos, in which provision is made for close fitting bushes to take care of any such controls, etc., which must of necessity pierce the bulkheads, and to prevent the passage of flames from the other side.

(2) To construct the whole of the engine mounting and the remainder of the structure in the immediate vicinity of the engine of fire-resisting material.

(3) To eliminate all rubber flexible joints and soft soldered joints in the petrol pipe lines on the engine side of the bulkhead.

(4) To ensure that all carburettor air intakes are taken outboard and exposed to the air stream so that any flames from backfires may be speedily extinguished. This position may not be the optimum in all cases from the engine point of view, but in this instance any slight disadvantage is outweighed by the consideration of fire risk.

(5) All exhaust manifolds to be taken outboard and exposed to the air stream and right away from the air intakes, any joints necessary to the exhaust system to be so constructed as to be flame-proof.

(6) All petrol and oil to be carried at the greatest possible distance from the engine.

(7) Induction systems to be designed and tested at pressures considerably in excess of any to which they are likely to be submitted in irregular running.

Accessibility.

It is obvious that if a part of an aircraft engine or installation requiring frequent maintenance attention is placed in an inaccessible position, the supervision necessary to ensure that such parts actually receive this attention must be increased, and in any case the chances are that the work will be inferior. Despite this fact, it is astonishing to note the usual inaccessibility not only of the parts but of the engine as a whole in many aircraft, particularly seaplanes.

An engine should be completely accessible with a minimum of dismantling of cowling, etc. On seaplanes, where the engine extends beyond the planes and overhangs the water, it is with considerable risk that any work can be done to the engine whilst afloat. For such cases it should be possible to provide, as standard equipment with the machine or as a fixture, a light folding staging, which could be suspended from the engine mounting or other convenient place.

In instances where it is necessary to stand on the planes to gain access to the engines, ample surface specially stiffened up to permit of walking, should be provided all round the engine. In some instances a tread plate will be provided here and there. It cannot be expected that a mechanic can do his work properly under such conditions, when he is in fear of damaging the planes if he moves.

An ample inspection cover or a piece of cowling, easily dismantled and large enough for easy access to the parts concerned, should be provided near such parts as carburettors, magnetos, petrol and oil filters, etc.

Cowling fasteners should be secure, but quick and easy to release.

All joints, bearings, levers, etc., in the engine control system should be easy of access for inspection, lubrication and adjustment.

It should be a comparatively easy operation to remove an engine bodily from the machine. This is a difficult operation on multi-engined machines with engine between the planes, and in such other cases where lifting apparatus cannot be

mounted directly over the engine. In these cases it would be a great advantage to the user if the designer took this matter into consideration in the early stages of his design. It might then have been possible to design an apparatus for inclusion in the ground equipment of the machine consisting, for example, of an extension of the engine bearers supported at the outer end from the ground on to which the engine could be drawn by a winding gear until it is far enough out to be picked up by a lifting gear. Some such apparatus would be invaluable when engine removal in the field is necessary.

Engine Starting and the Ignition System.

Arrangements in use for starting engines are varied:—

(*a*) The old and dangerous method of swinging the propeller by hand.

(*b*) A hand turning gear fitted to the engine, operated in conjunction with a hand turning magneto.

(*c*) Electric motor to turn the engine, in conjunction with a hand-starting magneto.

(*d*) The external motor-driven starter as represented by the Hucks starter, whereby a shaft driven by a car or lorry engine is made to engage by a dog or spider coupling with the airscrew shaft.

Of these, the first method is dangerous to the operator and is rapidly going out of use except for small rotary engines; in fact, it is not practicable to start the majority of the high-powered engines in use to-day by this means.

With methods (*a*), (*b*) and (*c*) "doping" is adopted before trying to start the engine, this consisting of pumping petrol or a petrol air mixture directly into the induction pipes. The engine is then rotated a few revolutions with the switches off until the "dope" has become distributed to the cylinders. Whilst it is still turning a hand-starting magneto is operated. This is connected to the sparking plugs via the engine magneto. A central terminal in the engine magneto distributor, to which the starting magneto is connected, is in turn connected to a metal point fixed in the distributor rotar at a point so that it trails at 30° behind the ordinary distributor brush. The trailing point being fixed in this position, firing from the hand-starting magneto occurs late at the sparking plug, so that there is no danger from backfires either to the operator turning the hand gear or to the electric motor, as the case may be.

It is the usual practice to fix the starting magneto and switch near the engine so that the operator starting the engine has them under his control. This arrangement appears to work well, provided that every precaution is taken to keep "off" the engine switches until the actual starting moment.

Method (*d*), *i.e.*, the employment of a Hucks starter, is undoubtedly efficient at terminal aerodromes where a large number of machines are to be started at different times. It is obviously impracticable, however, for general use and can only be regarded as an isolated expedient.

It is my view, therefore, that in future we must concentrate on the auxiliary engine starter, with which promising results are already in sight. Briefly, the system now in use consists of a small air-cooled two-cylinder unit, one cylinder serving only as a pump and connected by a distributor valve to each of the main engine cylinders in turn. The pressure developed is sufficient within a few seconds to start up the auxiliary engine and to turn the main engine, filling the cylinders at the same time with a suitable explosive mixture, the auxiliary engine pumping cylinder being fed from the small engine carburettor.

DISCUSSION.

Mr. F. HANDLEY-PAGE, who, at the request of the Chairman, opened the discussion, said that he felt the paper was a very solid contribution to engineering and aeronautical knowledge, and for that the Society was greatly indebted to the Author. Most of the difficulties with which those concerned with civil aviation had to contend were due to engine installation, and a good deal of them would have been avoided earlier had there been the closer co-operation between the engine designer and the aeronautical engineer of which the author had spoken. In the days of the war that was extremely difficult. He remembered his firm were engaged in making aircraft during the war, and Messrs. Rolls-Royce were making engines, but his firm were not allowed under any circumstances to communicate with Messrs. Rolls-Royce. They were both engaged on a job so secret and special, each for himself, that co-operation was impossible. He was speaking of the earlier days of the war, and under those conditions it was very difficult to impress upon an engine manufacturer what an aircraft designer wanted.

He had always found that the engine was the bugbear of the aircraft designer. It must be put at such a height that the propeller would clear the ground, and that, unfortunately, generally did away with the possibility of having gravity feed for the whole petrol system. That could be minimised to a certain extent by putting the carburettors lower down, but if they could have an engine with cylinders upside down—that is, projecting downwards instead of upwards as now—carburettors would be lower down, radiator lower down. With such an arrangement, quite apart from reducing petrol and water difficulties, it would give a very much better view for the pilot. From a civil aviation point of view—an operational point of view—when one saw a picture of a multi-engine installation, as illustrated by the lecturer, one was rather terrified at the expense and the difficulty of keeping it in operation, and it made one feel that an aeronautical Geddes committee was necessary to deal with it before one could operate it with any feeling of commercial success. The ideal arrangement would seem to be that in which they had an air-cooled engine, with the petrol tank sufficiently high above it so that it would feed direct on to the carburettor, and the pilot sitting close beside the engine so that all controls were at hand. Invariably he found that the breakdowns that occurred were due to the engine installation system. He again thanked the Author for his paper, which was the most interesting, from a practical point of view, that the Society had listened to for a long time.

Captain WILKINSON said he took it to be agreed by most people that the bulk of the trouble in an aeroplane was due to the engine installation. The engine being the bugbear of the designer of aircraft, the aeroplane installation was the bugbear of the engine designer, so that if the aeroplane and engine designers could get together and agree on a number of points at which the engine could be best attached to the aeroplane, to attach controls, petrol pipes, ignition wires, and so on, it would be possible to have one, two or perhaps three different types of installation for a given engine to cover all types of aeroplane. The engine builder could then put a large amount of the installation into his engine unit, so that a lot of the aeroplane designer's trouble would be eliminated and taken over by the engine builder.

Major-General Sir SEFTON BRANCKER first congratulated the Air Minister on his selection of Brigadier-General Bagnall-Wild for the appointment of Director of Research, and he paid a tribute to the splendid work done for aviation by General Bagnall-Wild from the first inception of the A.I.D. in 1913.

General Brancker said that he wanted to stir up the engine makers. He considered it perfectly ridiculous that at this stage in the development of aviation we should still be flying about carrying several gallons of water and an intricate cooling system which was eternally giving trouble; the water was always either freezing or boiling when it was least wanted to, and the system was a constant source of forced landings. He knew that the experts would contend that water-cooled engines effected a saving in fuel, but personally he was all for the air-cooled engine, and he felt that sufficient energy had not been devoted to the problem of reducing the fuel consumption of the air-cooled engine. For long journeys no doubt the water-cooled engine was the most economical for fuel consumption, but for a trip of two or three hours, which he considered the proper length of a stage in a heavier-than-air craft, he believed that the fuel consumption of an air-cooled engine could be reduced sufficiently to compensate amply any increase of the weight of fuel involved thereby, and so get rid of the various weaknesses of radiators, lengthy water-piping, and so on. In his recollection, the engine which ran best in the East was the old R.A.F.4, which went round like a clock whether the temperature was 120° in the shade or freezing hard; it was only necessary to alter slightly the jet, according to the season of the year.

The lecturer had made a novel suggestion; he had said that he thought at the end of each stage in an air route the engine should be changed instead of the passengers and cargo. This appeared to General Brancker to be a most excellent idea, but instead of two hours mentioned as the time necessary for the change by the lecturer, he thought it ought to take about ten minutes. In such a system the introduction of an air-cooled engine would help a good deal.

About three years ago, Captain de Haviland and Captain Wilkinson between them had evolved a method of fitting an air-cooled engine by which it could be removed from the aeroplane with very little trouble. It was merely necessary to undo four bolts, disconnect the pipes and controls, and remove the whole of the engine unit. He felt sure that if engineers would only devote their brains to the evolution of this sort of installation, the change could be effected in ten minutes.

He thought that the Germans had been always rather ahead of us in installation; their installations during the war possessed a sort of brutal simplicity which we had never attained; and he believed that to-day the Fokker, which is flying between Amsterdam and London, was every bit as good, if not better, than anything we had produced in our latest machines in the way of installation.

Another very important item was the question of self-starting. He was just back from the East, and there two-seater machines were not allowed to fly alone over the desert, one reason being that at least four people were necessary to start a big water-cooled engine. This was all wrong; an engine should be started by one man, and he felt that here again our technical brains had not been applied with sufficient energy to developing a really dependable self-starter. In the East again, he had been very much impressed with the vital necessity of steel or copper, or some metal for petrol connections; the deterioration of rubber in the heat was the cause of many forced landings. To-day, in designing the details of installation, it was absolutely necessary to obtain simplicity and strength, even though a certain amount of extra weight was involved thereby. The loss of carrying power involved by this extra weight would be amply repaid by the saving in time, in labour, and in the salvage of forced landings.

Group Captain BRIGGS said he felt that closer co-operation between aircraft and engine designers would probably produce one of the best solutions of the troubles they all had to face. The lecturer had not mentioned exhaust manifolds. A great deal of trouble was experienced with these, and he believed it was in some measure due to the fact that the engine constructors made some parts thereof and provided for attachment, whilst the aircraft constructors made the remainder. In this instance co-operation would be an advantage. Some

simplification in petrol systems might probably result if engine designers were to adopt some reliable type of mechanical engine-driven pump and thereby dispense with wind-driven pumps and their attendant complications.

Lieut.-Colonel HECKSTALL SMITH said that as the information given in the lecture was of the greatest possible value, he would like to know whether such information was generally obtainable and whether any published data existed on breakdowns and accidents and the findings as to causes leading up to them.

Squadron-Leader MILEY said that the engine designer and the aircraft designer had blamed each other in the past for anything that went wrong, and now that they had discovered there was something lying between them, they both said that the trouble was due to the installation and the many miscellaneous parts that were necessary to enable the engine to run. It seemed, therefore, that there was room for some enterprising gentleman to start a new industry for the development of engine accessories, filters, pumps, pipe joints, and all those accessories which required so much improvement. The author had said that engines were very inaccessible in seaplanes. As a matter of fact, a great many seaplanes were in service in which engines were uncowled, and were quite easily accessible by standing on the lower plane. There were hundreds of these machines in service, and there were very few troubles on account of engine installation, in spite of the fact that the question of installing the petrol system was very much more difficult than was usually the case in the ordinary aeroplane. This was due to the fact that in seaplanes of the boat type it was necessary to carry the bulk of petrol very low in relation to the engine.

Major H. E. WIMPERIS agreed that installation had been one of the greatest difficulties in aircraft in the last six or seven years, and there was still room for improvement. The lecturer stated that he had put forward a departmental view as Director of Aircraft Inspection, but he was doing far more, because he had had a long personal experience of internal combustion engines of many kinds. Doubtless at the Air Conference in the following month we should learn the author's programme as Director of Research at the Air Ministry. He had rightly laid stress on the importance of fire prevention, and he (Major Wimperis) always desired that when that subject was mentioned, a tribute should be paid to the splendid work of Major Norman in that direction; he paid tribute, not only to Major Norman's technical knowledge, but to his marvellous courage in being willing to hazard the experiment of setting his engine alight in the air. Speaking of the gravity feed for petrol, he was a little surprised that the author had suggested placing the petrol tank some distance horizontally from the engine, because one could not help wondering how, in some fast-climbing machines, the gravity feed would still be able to give the requisite 18 inches of head. With regard to the table of temperature conditions in the paper, he thought it would be wiser, in considering a matter of that kind, not to take average temperatures, but the extremes. There was one point which might conceivably be new, even to the lecturer, with regard to engine installation, and that was the weird effect sometimes produced by the hand magneto on the pilot's compass. If the hand magneto happened to be left in a position in which the armature was across the poles on one occasion, and at right angles to the poles on another, the compass deviation changed appreciably. This might give a misleading result if the compass installation was, either by accident or any other cause, placed in the neighbourhood of the starting magneto.

Captain BURGOINE amplified the information given in the paper with regard to starting gears. Taking an engine of 500-600 h.p., it might be said that the hand-turning gear would weigh about 15 to 20 lbs., the electric-turning gear about 35 to 45 lbs., plus not less than 45 lbs. for the battery, whereas the R.A.E. starter engine described in the paper would weigh about 45 lbs. complete with accessories fitted on the engine. One starter could be used to start any number of main engines; that would weigh about 40 lbs.; and there would be an additional

weight of 5 or 6 lbs. for each main engine. The Hucks starter was very useful, but was not always available. With regard to ignition wiring, it was suggested in the paper that wires should be painted with distinctive colours. The author had seemed to have forgotten that the standard specification called for a colouring scheme; the colour for the ignition system was blue, and nothing but blue must be used for ignition leads. With regard to a gravity tank above the engine, he could not imagine a more dangerous installation than one shown in the screen.

Major BUCHANAN, speaking of the co-operation of engine and aircraft designers, said that the question was one of extreme difficulty, because, as mentioned by Mr. Handley Page, they had hitherto lived in watertight compartments. Even at the present time they were using engines in the Service which it was practically impossible to instal in such a way as to make every part definitely accessible. Their principal troubles were in connection with the water and petrol systems. With regard to a simple petrol system, it was quite possible, and no doubt practicable, in civil aviation to use a standard gravity petrol system. On Service machines, on the other hand, the problem was one of considerable difficulty, and even if it were possible, there were very serious differences of opinion as to whether or not it was advisable. Experience during the war had led pilots to the opinion that it was very unwise to put all their eggs in one basket, or all their petrol in one tank, and for that reason designers at that time adopted the practice of splitting up the petrol capacity in the aeroplane. That, naturally, led to complications of the petrol system. With regard to Captain Burgoine's remarks as to the petrol system, he would like to point out that the gravity tanks in that particular aircraft were carefully kept in airtight compartments so that there was no danger, except in a very bad crash, of the tanks getting anywhere near the engine. With regard to the cooling systems at the present time, there is a great deal of difference of opinion, and further, the requirements of civil aircraft were entirely different from those required for service. For instance, a Service aeroplane was required to take off the ground on the hottest day in summer and climb at its greatest climbing rate, but no such condition was imposed upon civil aeroplanes. The civil aircraft also had an advantage with regard to the fireproof bulkhead. In the Service aircraft there were such things as guns, ammunition boxes, schutes, compasses, and things of that sort, and in such cases a fireproof bulkhead would have to be of very small dimensions. He joined with Sir Sefton Brancker in maligning the water-cooled engine.

The CHAIRMAN said he was glad to hear the old air-cooled *v.* water-cooled engine discussion being revived by the engineers represented at the meeting that evening. It was a stimulating subject, and if he had at one time been responsible for some developments on the air-cooled side, that did not preclude him from holding the balance impartially and welcoming the winning champion. As regards details of installation, he did not know why the author had eliminated the suggestion of aluminium pipes. Would General Bagnall-Wild speak on this? The goldbeaters' skin joint seemed to promise well, but more as a temporary makeshift during the period of popularising the solid joint, which he believed was a better solution and when standardised would be cheap enough. From a fire point of view, everybody had been impressed by the accident to R.38 as to the effect of having petrol pipes near electric leads, when both might be broken by a crash, the broken pipes providing the petrol and the broken leads providing at the same place the spark due to interrupting a live circuit. One would like to see no accumulators used on an aeroplane. That might be difficult to ask for, in view of the sundries which the author had alluded to; but they were generally more likely to cause fire than anything else on the plane, except, possibly, the exhaust pipe. If they could get engines, no part of which were to be at a higher temperature than 330°C., fire from the exhaust pipe would be eliminated, and that was about half the risk. If they could make sure that an electric spark would

not occur just in the petrol vapour, he believed the other half would be eliminated and fire risk would be swept away from among the apprehensions of the passengers. He was pleased to feel that the members present had been really interested and moved to take part in the discussion initiated by the stimulating paper by Brigadier-General Bagnall-Wild. He called upon the author to reply to the discussion.

Brigadier-General BAGNALL-WILD, replying to the discussion, thanked the members for their remarks with regard to the paper, and expressed his gratification that the speakers in the discussion had been able to give him so much meat for thought. They had not put many questions to him; in fact, they had given a lot of interesting facts which did not need answering. There was only one question he need deal with, and that was the one put by the President, as to why he had not added aluminium as one of the materials for petrol pipe lines. The reason was because he was thinking, not only of land machines, but also of seaplanes, and in a machine at sea the use of aluminium presented some little difficulty.

At the conclusion of the discussion a hearty vote of thanks was accorded the author for his paper.

Communicated by Mr. L. COATALEN: Having regard to the remarks of Brigadier-General Bagnall-Wild on engine mounting, I think a form of mounting I have developed for aero engines will be of interest. This is really a natural development of the mounting I have used for many years for racing cars, where it is, of course, very necessary that the transmission and motor is not subjected to undue stress owing to the distortion of the frame of the vehicle in service at high speeds. Briefly, as applied to aero engines, my system may be described thus :—

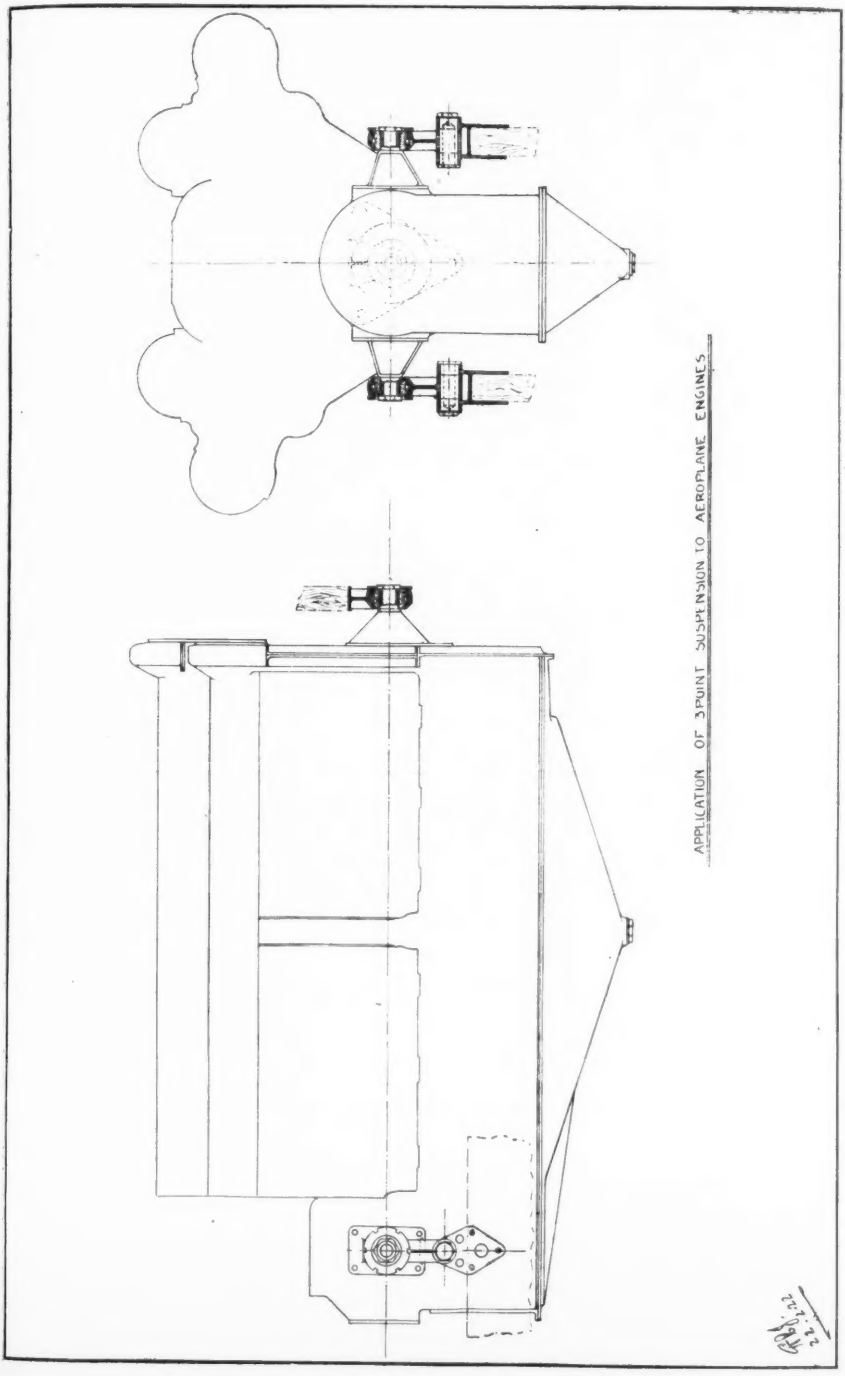
The portion of the engine crank case at the propeller end, and as near the propeller as possible, is provided with two horizontal trunnions, one on each side, and on the same axis, which is horizontal. These trunnions, which are bolted on to the crank case by flanges so as to distribute the load on the aluminium of the crank case, are spherical in form and fit into short vertical links, themselves carried by and turning on horizontal pins provided on the fuselage, preferably in way of the front cross member or bracing. These links are short and rigid, and are provided at one end with spherical bushings to take the trunnions and at the lower end with parallel bushes for the supporting pins. The other end of the engine is carried by one spherical trunnion as nearly as possible on the axis of the thrust of the propeller, which is fitted to a split spherical bracket rigidly mounted on the fuselage. There are two very important points to which I should like to call your particular attention *re* this mounting :—

(1) This is absolutely flexible whilst retaining those properties necessary for taking the torque and transmitting the thrust.

(2) It allows of quick dismounting and replacement of the engine.

The former is obtained by the three-point suspensions adopted combined with the link movements, which allow a longitudinal movement of any one point in relation to any other, and further it allows of the more common distortion of the fuselage in a rotary direction about its longitudinal axis, but at the same time by means of the two propeller end trunnions takes care of the full torque of the engine. Further, the position of the trunnions at the propeller end of the engine definitely locates the point of application of this torque, which allows of a more economical design of fuselage.

(2) The attachment of the motor to the fuselage by three points only naturally permits of a more rapid execution of the mounting and dismounting of a motor, whilst the design of mounting with links, etc., as described, avoids all necessity for lining up or bedding, etc.


APPLICATION OF 3 POINT SUSPENSION TO AEROPLANE ENGINES

The type of mounting referred to by the lecturer is apparently a 4-point mounting, to which any subsequent distortion of the fuselage would impose considerable stress on the engine crank case although the supports had been accurately lined up before mounting the motor, or alternatively, if the design of the fuselage is sufficiently flexible to avoid these stresses, the engine crank case is then subjected to the very serious stresses occasioned by landing, etc.

In addition to the above, an important point is that with the mounting described above, one cannot ensure that the torque is not transmitted through the crank case, as is the case with the more common form of mounting, owing to the deflection of the fuselage. It is practically impossible to design a fuselage so rigid that a certain amount of deflection does not take place, and it will be readily seen with this type of mounting the deflection of the fuselage does not impose any additional torsional stress on the crank case.

SPECIAL LIGHT WEIGHT AERO ENGINE.

A Lecture delivered by

MR. A. E. L. CHORLTON, C.B.E., M.INST.C.E., M.I.MECH.E., M.I.E.E., A.F.R.AË.S.,

Before the Scottish Branch on February 27th, 1922.

The high performance engine, whether military or commercial, is essentially the light one.

The motor which made flying possible was an internal combustion engine, and the basic reason of its success was the direct use of an easily volatile fuel of high heat value, namely, *petrol.*

The first engine developed to use this fuel was that of Daimler, and all motor-car, boat and aviation engines have sprung from this engine.

In order to more readily have in mind our problem, we can with advantage briefly run through the main aero engines so far constructed with the progressive results of tests.

The engine of Gottlieb Daimler is illustrated by Slide No. 1.* It had automatic inlet valves and exhaust governing, the latter being a point to be noted.

The next slide shows the engine of the Wright Brothers. This engine weighed 8.75 lbs. per B.H.P. inclusive; the most successful engine of to-day weighs under 3 lbs. inclusive.

A number of types then arose, such as the vee, fan, Y, fixed radial and rotary. The following engines illustrate these types:—V., Antoinette; Fan, Anzani; Y, Anzani; Fixed Radial, Salmson; Rotary, 80 Gnome.

The Gnome was at that time the engine most in favour, and as is well known, the Y type Anzani was used by Bleriot in the first cross-Channel flight.

Water-cooled engines were developed from motor-car practice, whilst other designs purely for aero work were in the main cooled direct by air. Thus we have many types and two systems. The various types are indicated in diagrammatic form by the next slide. To illustrate these types, the following figures may be noted.

The more important particulars of engines available in 1910 are given in Table I.,† and the engines which took part in the German trials of 1913 are shown in Table II.

Those entered for the British War Office competition in 1914 are given in Table III.

A number of typical engines are grouped and compared with similar piston speed and cylinder pressure in Table IV.

As I have indicated, the object of this lecture is to emphasise the importance of the light-weight engine as the line to be adopted for experimental work for future progress.

Let us consider the effect of the weight of the engine on the carrying capacity of a given machine. It will, of course, be obvious that for short flights, where little fuel has to be carried and the weight of fuel is small relatively to the

* These photographs are not printed.—ED.

† Printed at end of Lecture.—ED.

weight of the engine, the use of an engine of low weight per horse-power is of fundamental importance and economy is comparatively unimportant. It is also obvious that for very long flights where the weight of fuel to be carried becomes large relatively to the engine weight, low weight of engine is of less importance than economy of fuel and oil consumption. This is very clearly shown by the curves. The abscissæ represent hours run, and the ordinates weight of engine and fuel per horse-power in lbs. The performances of different engines are shown, and the heavier early German engines are compared with the light Gnome engine. It will be seen that for runs of anything over three hours the average German engine has the advantage, while below three hours' run the light engine gives an undoubted saving in weight and consequent greater carrying capacity, and would therefore seem a better commercial proposition.

As an example of the commercial importance of a low-weight engine we may consider a flight of 2½ hours, such as that required in the Paris service, which may fairly be taken as typical of the length of stage which will be required in commercial aviation. This length of flight would seem to be the most usual in charge of a single pilot. The following, though not quite up to date as regards fares, is very interesting.

Assuming power units of 500 B.H.P. with weights per B.H.P. 1.5, 2.5, and 3.5 lbs. with fuel and oil consumptions of 0.6, 0.5, and 0.45 lbs. respectively, the weight of power unit and fuel in the three cases would be :—

(*a*) 1,500 lbs.
(*b*) 1,875 lbs.
(*c*) 2,313 lbs.

With the lightest engine (*a*), therefore, the saving in weight would be 812 lbs., equivalent to five passengers, and with the medium-weight engine 437 lbs., equivalent to three passengers.

The earnings for fifty London-Paris flights at ten guineas per passenger are given in Table V.

It will be seen from this table that the total net earnings in the case of the lightest engine will be £4,125; in the case of the medium engine £3,304 3s. 4d.; and in the case of the heavy engine £1,833 7s.

The earnings for a given carrying capacity, it will be noted, are very large in proportion to any fuel costs likely to be incurred even in the most wasteful of engines as regards consumption.

In this calculation no account has been taken of the initial cost, as this is independent of type and with greater development may well be in favour of the lighter engine.

The provision and maintenance of a given number of engines in working order is allowed for in the renewals and replacement item. These figures very clearly show that for flights such as those required on the London-Paris services, light weight per H.P. is of the first importance.

It has been assumed that the consumption in the light-weight engine is very much greater than that in the heavier engine. With further development of the lighter types this is by no means necessary, and improvements in fuel consumption would obviously increase the balance in favour of light weight.

In this service it is shown how it is the light-weight engine that is the commercial one, and it must be our object to design such and make it fully reliable.

It is rather strange that this view is only now coming to be fully appreciated, for immediately after the war all that we heard was let us have strong and reliable engines, the weight is not so important.

Let us now consider the possibility of reduction in weight from the information available to-day.

We may now consider the question under three heads :—

1. Thermodynamical.
2. Mechanical.
3. Metallurgical.

Dealing first with thermodynamical considerations, up to the present aero engines work almost universally on the four-stroke constant volume cycle with equal expansion and compression, and any departures which have been made from this cycle must be regarded as purely experimental. The power developed by any given cylinder depends on the volumetric efficiency; large valve area and efficient cooling are the governing factors.

There is very little gain to be expected in this direction, though a mean effective pressure of 130 lbs. per square inch has been exceeded, and this figure has been used in our review.

By means of supercharging, weight reduction is more hopeful, particularly if done by fluid pressure alone.

Clerk's supercompression engine is shown by the next slide. The two diagrams on the next figure indicate the increase in the mean effective pressure he obtained by supercharging. A fluid compression method, in which the exhaust pressure in one cylinder is blown through a cooler into another cylinder at the phase of its cycle at which the extra charge is required, is shown at Slide 30.

Some additional cooling will be required on the main cylinder though flame temperatures are lower *per se*.

It may be that a reduction in weight of as much as 15 per cent. to 20 per cent. will ultimately be obtained by supercharging.

The question of cycles, two-stroke instead of four, is probably a change by which still greater reductions may be achieved; the use of the solid injection of fuel into the cylinder having very much increased the prospects of the two-stroke. More experimental work is wanted in both methods as the thermal limit (heat dissipation) so often intervenes.

Mechanically.—The reduction in weight by mechanical means must in the main be obtained by increased piston speed.

Increase of piston speed to obtain weight reduction has different effects in different types of engines or sets up different limitations. The limits are thermal and mechanical. For all types increased piston speed means more power per cylinder and therefore more heat flow, and increased cooling facilities must be provided. This is probably felt more in the air-cooled than in the water-cooled type; however, up to the present, heat dissipation has not proved to be a limiting factor. An experimental cylinder of 8in. bore by 10in. stroke has been constructed at the R.A.E. It has an aluminium head cast on to a steel barrel; the section of the head is spherical and four valves are fitted—two inlet and two exhaust.

There are certain limiting features in the speeds of engines, notably the loading at the big end of the connecting rod, and Table VI. is interesting, therefore, and reveals the state of affairs very clearly. It will be seen that the simple six can be run very much faster than the single plane radial—a point hardly sufficiently realised when comparing types. Further, if other considerations did not in turn become limiting factors, it is indicated that there is less difference between the weights of various types than is usually supposed. In examining this important limitation four engines were assumed, each having a capacity of 1,200 cubic inches, stroke bore ratio of 11 to 1, and a piston speed of 2,000 feet per minute.

The figures in Table VI. indicate that though the radial type may be the lighter in design, it is not necessarily so in practice, due to the crank pin load.

The rotary radial is limited by the centrifugal load of the cylinders and reciprocating parts and loss of power in rotation.

On the other hand, the plain six-cylinder line ahead, one of the most reliable of engines, can, other things being equal, increase its piston speed and so reduce its weight to 1.2 lbs. per B.H.P.; but this type may have difficulty with the valve gear when running at the higher rate of revolution to give the piston speed, and the necessary gearing required to give a reasonable propeller speed is no small problem.

Gearing is almost essential with all high-speed engines, and if added to the engines in the table now without it a material difference is made.

The Differential type combines the rotary and radial and reduction gearing, thus largely obviating the crank pin loading difficulty.

Valve gear operation and port area imposes a limit in all types. The crank pin load has different degrees of limiting effect on different types as has been shown, and the effect of counteracting forces such as the employment of centrifugal force to overcome this has been considered; similarly, centrifugal force was in the differential engine used with an all-tension valve gear. This allowed of a considerable reduction in weight, and hence a higher speed of gear. The sleeve valve as used in the Argyll engine illustrated by the next slide must also be considered.

The maintenance of volumetric efficiency is a difficult problem when the cylinder head already seems to be full of valves, and other types of construction may need to be adopted such as the principle used in the Monosoupape Gnome.

All valves may be used alternately for admission and exhaust with mechanical injection of fuel into the cylinder; to allow of the coupling up of pipework a director valve exterior to the valves on the combustion head must be used.

The indications are for dual purpose valves with direct injection of fuel for very high speeds.

Metallurgical.—We have now to consider the question of reducing of weight metallurgically. A table of specific gravities is shown* at Slide No. 34, and reveals considerably more possibilities than those so far considered; for instance, when we think of an engine like the 150 H.P. Gnome, shown at Slide No. 35, built entirely of steel having a specific gravity of 7.2, whereas that of the alloy electron is only 1.8, the prospects seem distinctly great.

The future of the light-weight alloys is not yet very clear with regard to the mechanical stresses they will ultimately be capable of carrying. If we suppose that in the course of time they can be produced so as to have a tensile strength of 40 tons per square inch and stand up to all other tests, fatigue included, that are obtained in the case of steel, then, of course, an extremely light engine seems possible below ½ lb. per brake horse-power.

In connection with this part of the subject, the work of the National Physical Laboratory has been most signal.

The Lecturer is very strongly of the opinion that more development work in the production of light-weight alloys should be taken by private firms. Up to now it has largely been done by the N.P.L. and public funds, though credit must be given to the Institute of Mechanical Engineers for their Light Weight Alloys Committee.

At the present time only certain parts of an engine can be made from light-weight alloys. In the vertical type this has been almost fully carried out. In the radial, for instance, on the Gnome, it would almost appear that a further 25 per cent. reduction on the 1 lb. could be made mainly on the crank case. From what has been said it seems quite possible to produce an engine under 1 lb. per brake horse-power.

* At end of paper.—Ed.

TABLE 1.

AERO ENGINES BEFORE 1910.

Name of Engine ...	Wright.	Antoinette.	Anzani.	Green.	Wolseley.	Pipe.	Aster.	Renault.	Panhard.	Gnome.
Type of Engine ...	Vertical.	Vee.	Fan.	Vertical.	Vee.	Vee.	Vertical.	Vertical.	Vertical.	Rotary.
Cooling System . .	Water.	Water.	Air.	Water.	Water.	Water.	Water.	Water.	Water.	Air.
Number of Cylinders	4	8	3	4	8	8	4	4	4	7
Bore of Cylinders, inches	4.25	4.35	3.94	5.52	3.74	3.94	5.12	4.33	7.28	4.35
Stroke of Piston, inches	4.33	4.15	5.92	5.75	5.0	3.94	5.52	6.30	7.88	4.73
Brake Horse-Power...	24	49	25	60	54	55	51	38.5	112	45
Brake M.E.P., lbs./ sq. in.	64.48	60.52	65.33	78.50	88.47	58.15	88.86	74.71	75.15	65.85
Revs. per Minute ...	1200	1100	1400	1100	1350	1950	1000	1100	900	1100
Piston Speed, ft. per min.	870	760	1380	1015	1125	1280	925	1155	1180	870
Dry Weight of Engine, lbs.	210	265	140	236	300	289	242	286	836	172
Weight per B.H.P. in lbs.	8.7	5.4	5.6	3.94	5.6	5.3	4.75	7.4	7.5	3.8

TA

PARTICULARS OF LEAD GINES

GERMAN AEROPL GINE T

MAKE OF ENGINE.		BENZ.	MERCEDES-DAIMLER.						ARG
Type		Vertical.	Vertical.	Vertical.	Vertical.	Vertical.	Vertical.	Vertical.	Vert
Number of Cylinders	No.	4	6	4	4	4	6	4	
Bore of Cylinders ...	inches	5.12	4.13	4.72	5.51	4.72	4.72	4.33	5.51
Stroke of Pistons ...	inches	7.09	5.51	5.51	5.90	5.51	5.51	5.51	5.51
Brake Horse-Power...	B.H.P.	101.2	88.9	71.3	99.1	70.4	103.0	60.8	6
Brake Mean Pressure	lbs./□"	107.0	114.2	103.5	102.0	107.5	107.0	104.8	9
Revs. per Minute ...	R.P.M.	1288	1387	1412	1373	1343	1315	1369	1
Piston Speed... ...	ft./min.	1523	1274	1297	1350	1233	1207	1282	1
Fuel per B.H.P. Hour	lb.	0.47	0.51	0.50	0.49	0.50	0.53	0.50	
Weight of Engine complete with Cooling System ...	lbs.	425	390	352	490	379	541	337	
Weight per B.H.P....	lbs.	4.20	4.37	4.91	4.91	5.36	5.23	5.51	
Weight of Power Plant with Fuel, Oil and Tanks for 4 Hours	lbs.	657	605	525	719	545	799	502	
Weight of Power Plant per B.H.P....	lbs.	6.48	6.81	7.37	7.25	7.74	8.21	8.26	

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PARTICULARS OF LEAD GINES

BRITISH W FFICE

MAKE OF ENGINE.		ARGYLL.	BRITISH ANZANI.	BEARDMORE AUSTRO-DA		DUD IMSON C
Type		Vertical.	Radial.	Vertical.	Radial.	R
Number of Cylinders	No.	6	10	6	7	
Bore of Cylinders ...	inches	4.92	4.53	4.72	4.72	
Stroke of Pistons ...	inches	6.89	6.10	5.51	5.51	
Brake Horse-Power...	B.H.P.	116.6	100.2	95.5	120.0	12
Brake Mean Pressure	lbs./□"	97.2	72.5	102.0	92.3	8
Revs. per Minute ...	R.P.M.	1200	1110	1279	1275	1
Piston Speed ...	ft./min.	1378	1129	1175	1171	1
Fuel per B.H.P. Hour	lb.	0.57	0.95	0.69	0.58	
Weight of Engine complete with Cooling System ...	lbs.	600.0	464.0	437.1	582.9	5
Weight per B.H.P....	lbs.	5.15	4.64	4.68	4.86	
Weight of Power Plant with Fuel, Oil and Tanks for 4 Hours	lbs.	919.2	958.7	738.1	901.9	8
Weight of Power Plant, etc., per B.H.P.	lbs.	7.9	9.5	7.7	7.55	

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TA
LEAD GINES IN 1914. TEST FIGURES.
ROPL GINE TRIALS, 1913.

	ARGUS.		N.A.G.		MULAG.	SCHROTER.	BAYER-ISCHEN.	GYRO.
al. Ve ical.	Vertical.	Vertical.	Vertical.	Vertical.	Vertical.	Vertical.	Rotary.	Rotary.
	4	6	4	4	6	6	7	7
3 51	4.92	4.92	5.31	4.72	4.33	4.88	4.33	4.29
I 51	5.12	5.12	6.30	4.72	6.69	6.30	4.72	4.76
.6	71.0	102.0	95.6	95.8	101.7	88.7	37.4	38.7
.4	107.5	101.1	101.0	95.0	101.1	79.2	66.6	77.0
8	1342	1370	1344	1408	1346	1252	1031	954
6	1145	1169	1109	1400	1557	1314	812	757
0 53	0.59	0.59	0.52	0.49	0.53	0.63	0.86	0.77
27	357	536	279	476	588	468	177	186
I 40	5.00	5.22	4.96	4.98	5.76	5.27	4.72	4.80
02	566	829	409	696	834	705	340	351
6 16	7.98	8.12	7.33	7.28	8.21	7.94	9.10	9.07

TA
EAD GINES IN 1914. TEST FIGURES.
SH W FFICE TRIALS, 1914.

DMOR -DAL	DUDBRIDGE MSON	CANTON-UNNE.	BRITISH GNOME MONOSOUPAPE.		GREEN.		SUNBEAM.	WOLSELEY. F2.	RENAULT.
. Ver dial.	Radial.	Radial.	Rotary.	Rotary.	Vertical.	Vertical.	Vee.	Vee.	Vee.
7	9	14	9	9	6	6	8	8	12
4.72	4.72	4.72	4.13	4.13	5.51	5.51	3.54	5.00	3.78
5.51	5.51	5.51	5.90	5.90	5.98	5.98	5.90	7.00	5.51
0.0	124.0	185.0	96.2	104.2	101.7	103.5	130.9	139.6	113.5
2.3	89.0	83.5	92.0	96.0	75.5	77.0	108.7	81.0	67.3
75	1276	1307	1206	1205	1246	1242	2046	1238	1800
71	1172	1200	1187	1186	1243	1239	2014	1445	1654
.58	0.55	0.61	0.69	0.72	0.67	0.63	0.53	0.58	0.66
2.9	545.6	780.2	275.0	275.0	506.1	507.3	565.1	810.7	478.8
4.86	4.40	4.22	2.77	2.64	4.97	4.90	4.32	5.81	4.22
1.9	871.5	1303.9	655.4	716.0	835.2	818.2	896.1	1190.6	863.2
7.55	7.20	6.95	6.60	6.86	8.22	7.91	6.84	8.54	7.60

TABLE 4.

COMPARATIVE TABLE OF TYPES.

TYPE OF ENGINE.	NAME OF ENGINE.	PERFORMANCE AT NORMAL PISTON SPEED AND NORMAL BRAKE MEAN PRESSURE.					PERFORMANCE WITH NORMAL PISTON SPEED AND 130LBS. PER SQ. IN. B.M.E.P.			PERFORMANCE WITH NORMAL B.M.E.P. AND PISTON SPEED OF 2,000FT./MIN.			PERFORMANCE WITH PISTON SPEED 2,000FT./MIN. AND B.M.E.P. OF 130LBS.		
		Weight per B.H.P. in lbs.	R.P.M.	Piston Speed Feet/Min.	B.M.E.P. Lbs. per sq. in.	B.H.P.	Weight per B.H.P. in lbs.	R.P.M.	B.H.P.	Weight Lbs./ B.H.P.	R.P.M.	B.H.P.	Weight Lbs./ B.H.P.	R.P.M.	B.H.P.
Vertical Water Cooled	"Puma"	3.25	1400	1746	118.1	240	2.96	1400	264	2.84	1605	275	2.50	1605	312
Vee Water Cooled ...	300 h.p. Hispano Suiza	2.65	1800	1770	116.8	300	2.38	1800	334	2.34	2160	339	1.99	2160	400
Vee Water Cooled ...	Rolls-Royce Eagle ...	3.37	1800	1950	124.0	350	3.21	1800	367	3.28	1847	359	3.13	1847	376
Vee Water Cooled ...	Liberty	2.69	1650	1925	118.0	405	2.44	1650	446	2.59	1715	420	2.34	1715	464
Arrow Water Cooled	Napier "Lion" ...	2.57	2000	1710	122.0	450	2.40	2000	480	2.19	2340	526	2.06	2340	561
Rotary Air Cooled ...	B.R.2	2.10	1300	1536	95.2	238	1.53	1300	325	1.60	1690	310	1.17	1690	425
Radial Air Cooled ...	Cosmos "Jupiter" ...	1.75	1650	2060	109.5	400	1.47	1650	475	1.80	1600	388	1.52	1600	460

TABLE 5.

LONDON-PARIS SERVICE.

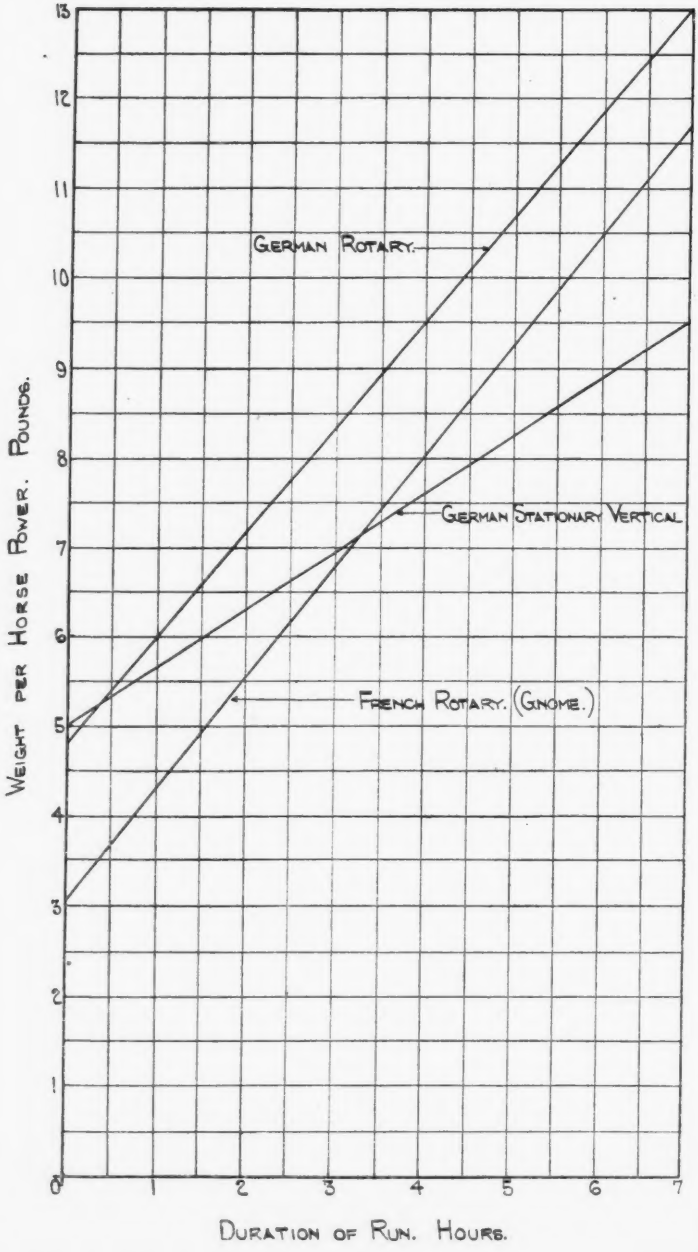
		a	*b*	*c*
Type of Engine	—			
Brake Horse Power of Engine	B.H.P.	500	500	500
Weight per B.H.P.	lbs.	1.5	2.5	3.5
Fuel and Oil Consumption per B.H.P. Hour	lbs.	0.6	0.5	0.45
Weight of Power Unit, Fuel, and Oil, for 2½ Hours	lbs.	1500	1875	2312
Weight of 5 Passengers at 160 lbs. Each	lbs.	800	800	800
Weight of Power Unit, 5 Passengers, Fuel and Oil for 2½ Hours	lbs.	2300	2675	3112
Saving of Weight Based on Engine "C"	lbs.	812	437	nil.
Number of Passengers Equivalent to Saving of Weight	—	5	3	nil.
Total Number of Passengers that could be Carried	—	10	8	5
Total Earnings at £10 10s. 0d. per Passenger for 50 Flights	—	£5250	£4200	£2625
Running Time Allowed between Overhauls	Hours.	50	100	150
Total Running Time for 50 Flights	Hours.	125	125	125
Number of Overhauls	—	2.5	1.25	0.83
Cost of Upkeep and Replacements assuming £50 per Overhaul	—	£125 0 0	£62 10 0	£41 13 0
Cost of Fuel at 4/- per Gallon for 50 Flights	—	£1000 0 0	£833 6 8	£750 0 0
Total Cost for 50 Flights	—	£1125 0 0	£895 16 8	£791 13 0
Nett Earnings for 50 Flights	—	£4125 0 0	£3304 3 4	£1833 7 0

TABLE 6.

Engine		*a*	*b*	*c*	*d*
Type of Engine		Vertical.	Vee.	Arrow.	Radial.
Number of Cylinders	No.	6	12	12	9
Bore of Cylinders	inches	6.00	4.78	4.78	5.25
Stroke of Pistons	inches	7.00	5.60	5.60	6.14
R.P.M. at Piston Speed of 2,000 Feet per Minute	R.P.M.	1715	2140	2140	1960
Rotary Weights	lbs.	5.10	5.82	7.45	16.4
Centrifugal Pressures	lbs.	1490	2120	2720	5480
Diameter of Crank Pin	inches	2.52	2.15	2.20	2.62
Effective Length of Bearing	inches	2.90	2.30	2.50	3.10
Projected Area	sq. ins.	7.50	4.95	5.50	8.12
Centrifugal Loading on Big End Bearing	lbs./sq. ins.	200	433	495	675
Rubbing Velocity	ft./sec.	18.85	20.10	20.50	22.40
Load Factor	lbs. ft./sec.	3770	8700	10150	15100
Permissible Increase in R.P.M. for Constant Centrifugal Loading (*d*)	Per Cent.	84	25	17	0
Permissible Increase in R.P.M. for Constant Load Factor (*d*)	Per Cent.	59	20	14	0

TABLE 7.

SPECIFIC GRAVITIES OF VARIOUS METALS.

Lead	11.0
Copper	8.9
Nickel	8.7
Bronze	8.7
Steel	7.8
Wrought Iron	7.7
Cast Iron	7.5
Manganese	7.4
Tin	7.0
Zinc	7.0
Chromium	6.8
Antimony	6.6
Aluminium (Commercial)	2.6
Magnesium	1.75

CURVES SHEWING INITIAL WEIGHT PER HORSE POWER AND DURATION OF RUN.